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Part 1

SHUTTLE USER ANALYSIS (STUDY 2.2)

FINAL REPORT

Volume III: Business Risk and Value of Operations In Space (BRAVO)

Part 1: Summary

Prepared by

Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

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FOREWORD

The Shuttle User Analysis (Study 2.2) Final Report is comprised of four volumes, which are titled as follows:

Volume I - Executive Summary

Volume II - User Charge Analysis

Volume III - Business Risk and Value of Operations In Space (BRAVO)

- Part 1 - Summary
- Part 2 - User's Manual
- Part 3 - Workbook
- Part 4 - Computer Programs and Data Look-Up

Volume IV - Standardized Subsystem Modules Analysis

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1. INTRODUCTION

The objective of the Business Risk and Value of Operations In Space (BRAVO) effort has been to develop, test, and document a tool which is capable of answering questions of potential users of space systems regarding:

1. Is a space system or terrestrial system better for a particular application?

2. Which of two or more space systems is better for a particular application?

The questions are turned into specific problem statements and quantitative results obtained with the BRAVO tool.

The Final Report of the Business Risk and Value of Operations In Space (BRAVO) study consists of four parts. Part 1 summarizes the study and contains useful background information emphasizing the philosophy behind the analytical techniques. It describes the approached used in the study, the operation of the various analytical procedures, and the development and testing of BRAVO in a general way. An overview of the BRAVO procedure itself is given in Section 2 of Part 2, the User's Manual. Part 3 contains a series of worksheets, some or all of which may be required to work each specific BRAVO problem. It is intended that, for each problem, the user start with a clean set of the appropriate forms from Part 3. The completed forms then become part of the record of each analysis. Part 4 contains the computer program listings and additional data banks required to operate the BRAVO procedures.

NASA is interested in contacting potential future users of space systems and responding to the questions and/or needs of these potential STS customers. NASA's desire is to be able to respond rapidly

with minimum expenditure. Typically, users' questions and needs revolve around differences in cost, schedule and risk between planning the expansion or product improvement for their product or service by utilization of space systems. The question may be whether to use a space system or a terrestrial system or the question may be which is the best of two or more space systems for the application. Valid answers are needed using proven techniques.

The BRAVO approach brings the user closer to the analysis. This advantage is thought to be unique. User inputs are used directly in setting up the analysis problem. The output of the analysis is primarily cost information and data which can be understood by most potential space users. Therefore, little understanding of space systems per se is required for the user to understand the study results. When the potential user establishes the demand for a function or service to be performed, it is presumed to be described in a manner reflecting his own assessments of the market for his particular products or services. Therefore, the results of the analysis fit directly into the potential user's planning and thinking. It is also quite possible that the techniques developed for the BRAVO tool could be employed by a user directly to do an independent analysis.

2. DEFINITION OF BRAVO

The name BRAVO refers to an analytical tool comprised of a very large data bank which has been organized and correlated so that it can be applied to specific space systems and ground systems configured to and responsive to users' needs. The procedures are designed to accept user's-need type inputs, define space systems and ground systems which will fulfill users' needs at comparable risks, and, finally, make economic comparisons between the ground system and space system.

The BRAVO analyses are carried out by a procedure which has been made routine. The full-blown procedure has nine routine steps; four of which are computer programs, and five of which are accomplished using formalized check lists or manual calculation procedures. Three additional steps have been identified and described which are required to make up for imperfections in the user's description of his problem and also to provide for interpretation of results. These latter three steps are accomplished using similarity techniques (similar system concept and data look-up) and applying systems engineering, judgment, and experience.

The BRAVO tool fits problems best which can make use of current technology or extensions of current technology. It also can be adapted to applications requiring advanced technology when technology studies are available or can be made which define the advanced technology goals.

The BRAVO tool is intended for automated and manned satellite systems. In its current form, the BRAVO tool works best on application types of satellites intended for operation over a long period, i.e., communication systems, navigation systems, weather and earth observation systems, and normal variations and combinations of these. Its

adaptability has been demonstrated by applying ti to a solar cell power satellite system of advanced design. The BRAVO tool also has been tested by applying it to two communications satellite systems and an earth observation system, each launched by the STS. Parallel studies were or are being carried out by other organizations for each of these three systems, thus providing a means of checking the BRAVO analysis results.

3. BRAVO APPROACH

The BRAVO tool considers the function of the system, system risk, and system cost in making comparisons between ground systems and space systems, or comparisons between two or more different space systems. The approach taken in developing the tool is that a competing ground system and a space system should have equal capability to perform the function or service desired by the potential user if they are to be compared. The risks also are made as nearly equal as possible between the space system and the ground system to be compared. One way this is accomplished is to configure the space system to have a risk equal to the ground system or the user's specified risk (usually system outage allowance). With the STS as the space system launch vehicle, the risk associated with the system varies with satellite logistics (e.g., frequency of launch), or satellite reliability, or both. With the STS, the satellite development risk also can be varied with changes in the development approach and expenditure, although the latter is not as significant as the outage problem[1].

When the capability and risk are equal, the system costs can be compared using economic analysis techniques.

The approach for development of BRAVO techniques includes testing the analytical tool against other studies on the same user needs. Reasonable agreement can be expected between two studies utilizing different data banks and techniques if the inputs and ground rules are the same.

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(1) Development programs have been funded historically at a level consistent with their historical operating success. It is the historical operating success which is being represented in this analysis.

Ground rules for the BRAVO procedures include the following:

1. The lowest cost approach for each system is utilized. In order to accomplish this, the alternative system approaches are configured, costed, and compared as a part of the routine procedure. For instance, in a specific application, if the analyst is not sure whether the lowest cost approach would include spare satellites on orbit or not, both alternatives would be analyzed and the lowest cost approach meeting system requirements would be chosen.

2. Unless the potential user specifies that a dedicated system is needed, the analysis considers shared system capability as well as dedicated systems for the application. Again, the choice between the two is made on the basis of minimum cost.

3. It is assumed that the space systems to be analyzed will be operating in the space transportation system era, most likely 1985 or later. Several potential advantages for space systems are foreseen for the STS era:

    a. Space system risks will be decreasing with the STS capability

    b. Space system buy-in costs may be decreasing

    c. Space system applications activity level has a potential for increasing

    d. Space system development lead times have a potential for decreasing.

4. It is assumed that the user will accept payload designs which follow design rules for STS payloads. Design rules for STS payloads may be found in References 1, 2, and 3 and in Section 4.3, Part 2, Volume III of this report.

5. It is assumed in the economic analysis that no major surprises occur, such as large-scale warfare or a large-scale depression in the economy.

4. OPERATION OF BRAVO PROCEDURES

The detailed explanation of BRAVO procedures is contained in the User's Manual, Part 2 of this volume. In order to accomplish these analyses, personnel with certain skills are required. The two lead personnel in the analysis are the space systems concept analyst and the ground systems concept analyst. These analysts should have broad technical backgrounds and considerable systems experience in the appropriate areas. They will both require the assistance of a systems cost estimator, and for some problems may need on-call or consulting help from specialists such as a telecommunications engineer, radar, microwave or IR engineers, and computer program operators. For the ground systems, manual calculator operator assistance may be required. For the space systems, personnel trained in the IBM APL interactive computer program operation and on the CDC 7600, as well as manual calculation assistance, are needed. The space system concept analyst also will need part-time specific tasks accomplished by a satellite design specialist, a cost estimator, and a reliability engineer. An economist also will be helpful in interpreting and/or iterating the results of the economic analysis comparisons.

5. STATUS OF BRAVO DEVELOPMENT AND TESTING

The BRAVO capability is sufficient to analyze most normal space systems (meeting the limitations, i.e., automated, application-type space systems, etc.) and comparable ground systems when the user specifies the mission equipment. The BRAVO capability developed to date also includes synthesis of channel-type communications system mission equipment where the user has not specified the mission equipment. The mission equipment synthesis is accomplished with BRAVO procedures using the potential user needs as requirements. The BRAVO capability also includes the data for making estimates on earth observation satellite mission equipment characteristics appropriate for systems in the 1980s.

The BRAVO tool has been tested by (1) applying it to future international communications satellites and comparing analyses with those of the Comsat Corporation, (2) applying it to a solar cell power satellite of advanced design and comparing results with similar studies by A. D. Little and associated contractors. Agreement was good in both cases. The results of two other test cases will be known when the contractor studies are completed and the studies compared. These latter two test cases are (1) a BRAVO analysis of the same problem being considered in the TRW study on an STS-launched Defense Communication Satellite System, DSCS-II, and (2) a BRAVO analysis of the Earth Observation Satellite system being defined for the Goddard Space Flight Center (GSFC) by three contractors.

6. BRAVO OUTPUT AND ITS UTILITY

One type of question to be answered by a BRAVO analysis is, "When is it worthwhile going further with the space application in preference to the ground application to fulfill the user's needs?". The following rules of thumb are based largely on judgment.

1. If the first comparison between the space system and the ground system is close but not equal (one system has an advantage of 20 percent to 100 percent), further study and another iteration on the analysis may be useful, particularly if technology, changes in operating mode, or additional systems sharing can be identified which could influence the comparison.

2. After an iteration (if necessary), whichever system has a competitive advantage of approximately 20 percent or improvement in key economic parameters, e.g., peak indebtedness or revenue required to make the system profitable, would be considered the best approach to take.

3. If the space system and ground system are about equal (within $\pm$ 20 percent), then further study may be required to optimize, define, and reassess the economic comparison.

The economic advantages or disadvantages can be measured in many eays at the end of an analysis. One method for presenting the end result of a BRAVO analysis comparing a potential space application with a terrestrial system is illustrated in Figure 6-1. The cumulative cash flow over the period of installing and operating a particular system to meet an expected demand measures the return to the user on his investment in terms of cumulative cash and also shows the peak deficit cash flow encountered. Cash flow can be presented in either constant dollars or current (inflated) dollars, or both.

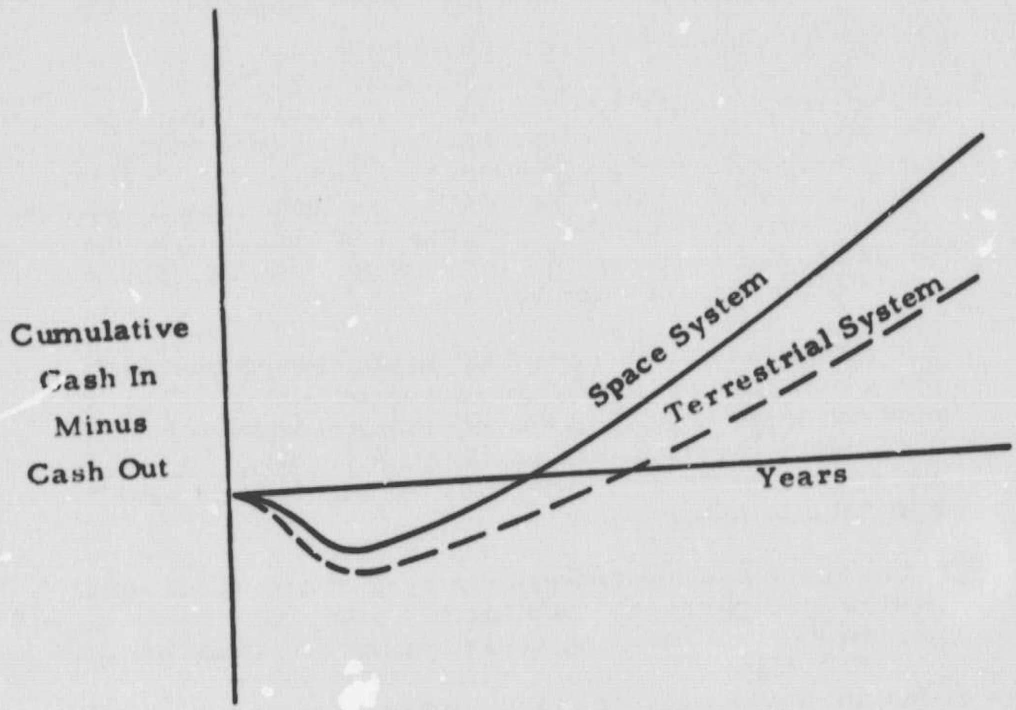

Figure 6-1. Cash Flow at Equal Demand, Equal Revenue, and Equal Risk

Another type of question to be answered by a BRAVO analysis is, "Considering several space system concepts, which concept is the most economical?". The results of a BRAVO analysis perfromed on the DSCS-II communications satellite system will illustrate the BRAVO output for selecting the most economical concept. The BRAVO problem was formulated to compare expendable satellite, ground refurbishable satellite, and space serviceable satellite systems. The communications equipment was specified as well as satellite orbits (four synchronous equatorial satellites), satellite type (three-axis stabilized designs), and minimum satellite system availability (90 percent).

The results are shown in summary form in Table 6-1. All launches are made with the Shuttle and full-capability Tug. Space servicing was used to accomplish on-orbit satellite maintenance through removal and replacement of one or more of the ten satellite modules. Satellites are retrieved when failure occurs in the non-modular portion.

The results indicate a significant savings (30 percent of total system costs) for the on-orbit service mode relative to expendable satellite operation.

Additional comparisons and tradeoffs were made in the analysis which illustrate the versatility of the BRAVO capability.

1. The number of modules was varied from 5 to 20 with insignificant effects on the system cost.

2. The effects of satellite wearout on the comparison was tested and found to have a significant effect on the number of launches and cost of the expendable satellite system.

3. The effect of increased satellite component redundancy was tested and found to have relatively small effects on the comparison.

Table 6-1. Comparison of DSCS-II Satellite System Modes Of Operation, Satellite Designed With Single Level Of Redundancy

Satellite Operational Mode	System Availability[1]	Number Of Satellite Launches	Total Cost Relative To Expendable Operation
Expendable	0.97	12.8	1.00
Ground Refurbishable	0.96	12.7	0.82
Space Serviceable	0.99	10.0	0.70

(1) $\dfrac{\text{System Up Time}}{\text{Up Time} + \text{Down Time}}$

Note: TRW DSCS-II results not yet available for comparison.

4. Dual-spin satellite design approaches were tested operating with ground refurbishment. Again, significant savings (approximately 30 percent relative to three-axis expendable satellites) are shown.

5. Three satellite systems were compared with four satellite systems. The availability for the space serviceable mode decreased from 0.999 to 0.93 (see Table 6-1) but still met the 0.90 requirement. The system costs were reduced by nine percent.

Thus, the BRAVO analysis results in not only system comparisons, but in tradeoff data needed for optimizing STS-supported satellite system concepts.

7. REFERENCES

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